International Journal of Engineering Education Vol. 31, No. 1(B), pp. 199–208, 2015
Printed in Great Britain

0949-149X/91 $3.00+0.00

PBL in the Teaching of Design in Aeronautical Engineering: Application and Evolution of a Consolidated Methodology*

J. L. PEREZ-BENEDITO*, J. PEREZ-ALVAREZ*,** and M. J. CASATI*
* Departamento de Aeronaves y Vehículos Espaciales, Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, Plaza del Cardenal Cisneros 3, 28040 Madrid (SPAIN).
** Instituto Universitario de Microgravedad Ignacio da Riva, Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, Plaza del Cardenal Cisneros 3, 28040 Madrid (SPAIN). E-mail: joseluis.perez@upm.es; javier.perez@upm.es; mariajesus.casati@upm.es

During the last few years of teaching the subject of Graphic Engineering, traditional teaching methods have been used based on lectures and solving any problems as they arose. In the opinion of the authors, this gave a rather compartmentalised overview of engineering design. Students were assessed solely by a final exam, the final mark only being slightly influenced by the exercises set throughout the course. Being aware of this deficiency and motivated by the large number of graduates absorbed by the industrial engineering sector, two different experiences were developed built around project-based learning (PBL). It was intended to introduce a consolidated method that would bring students closer to an environment that simulated the actual working conditions in the field of engineering design. This paper describes the evolution of the methodology proposed by the authors and the results achieved. The aim of the authors is not simply to establish a methodology that will serve as an integrative component between the different degrees but as a methodology that will forge cross-links between degree subjects and enable students to develop their work more fully and endow their vocational training with a wider scope.

Keywords: project-based learning (PBL); cooperative learning; collaborative learning; engineering design

1. Introduction

Companies not only require new technical school graduates to be qualified professionals with a solid technical background but also require these professionals to possess a set of aptitudes called generic skills. Teamwork, communication skills, leadership and critical thinking [1, 2] are all very positively evaluated by hiring officers. Nonetheless, various studies [3, 4] have brought to light major deficiencies in these aptitudes in the general context of university students.

The changes currently taking place in European university teaching to adapt to the European Higher Education Area (EHEA) are promoting a movement for the implementation of different techniques for transmitting knowledge, a movement to open the way to other more active methods where students can construct their own knowledge, in the hope that the learning process will be more meaningful and long-lasting.

This change of perspective in the profile of the future professional expert means changes need to be made to the way teaching methodologies have traditionally been conceived by supplementing them with more active techniques that will enhance and boost the procedure of transmitting knowledge and skills. In this respect, the Bologna Declaration [5] is very much in favour and puts forward and fosters this change of conception.

Achieving these goals is one of the main challenges faced by teachers who are committed to educational innovation where the learning becomes student-centered instead of teacher-centered [6, 7]. One of the methods that encourages and motivates students taking technology subjects to take an active role is project-based learning (PBL) [2, 8, 9].

PBL consists in supplementing the traditional teaching system with another of a collaborative nature where knowledge is acquired through more active student participation by involving the student in tasks that come close to actual vocational development, not only from the job point of view but also mainly from the point of view of the work environment.

Regarding the teaching of certain subjects, particularly those with a greater technological content, PBL has proved to be a highly versatile tool for the teacher as it fosters different skills, both general and specific. In engineering design [10], taking this in its widest sense, the project-based method leads to clear improvements in student training [11, 12, 13]. More specifically and as part of this method, cooperative work has proved to be an essential pillar that has a high educational potential [14].

As for generic skills, the Tuning Project [1, 15] brings out the major ones. Along these lines, it demonstrates the effectiveness of doing projects and embarking on them collaboratively to promote the development of some of the most important

* Accepted 15 July 2014.

skills, such as teamwork, organisation, leadership and the presentation of ideas, [16, 17].

2. Background

The subject of Graphic Engineering[1] (6 ECTS credits), taught on the last course of Universidad Politécnica de Madrid degree in Aeronautical Engineering integrates the different concepts relative to engineering design studied throughout the course. It integrates both participation in projects and graphic representation for the preparation of technical documentation.

Interpreting, creating and managing technical papers for conceptual, preliminary and detailed design are approached in the subject with a strong cross-linking to the other subjects of the course. These aspects endow the subject with a markedly practical focus.

In the preceding courses, student assessment centred on two aspects: individual work structured into practical classes plus a final exam. Having observed certain deficiencies in this model, the authors have sought a change oriented towards replacing the teaching methodology used up to then by another based on PBL that would simulate the actual job situation in aeronautical sector companies. The change undertaken is oriented towards a more active, applied and global form of approaching the subject.

The decision to apply the change to PBL-based training firstly had to be validated. Although the experiences examined referring to the success of PBL teaching were encouraging [9, 14, 15] a major factor in every one was a small number of students, which collided head on with the number of students registered in Graphic Engineering, which was around 200.

The authors considered the most sensible method was to divide the experience into two consecutive academic years.

In the first year the experience would not involve the whole group of students enrolled in Graphic Engineering. Only voluntary students participated in the experience and neither criterion was used for selecting them. But it would involve a sufficiently significant number so as not to condition the experience, while considering the remaining students as a control and validation group.

In the second year, and taking account of the previous results, the experience would be applicable to the whole group, thereby incorporating the student numbers factor to the experience and analysing any possible repercussions, either on the experience or on the results. We will now develop and analyse the two experiences approached.

[1] http://ocw.upm.es/expresion-grafica-en-la-ingenieria/ingenieria-grafica-metodologias-de-diseno-para-proyectos

3. First experience

3.1 Approach

The first experience was approached from an entrepreneurial perspective where the work reality of the aeronautical companies' department responsible for design work was simulated. Training was set up for two companies, each organised into three design departments. The overall purpose was to develop three aeronautical design projects that shared common ground. This generated different kinds of inter-relationships and a global view of the experience [12].

Three design tasks were chosen (called business lines) which, because of their nature, could be developed with between 40% and 50% of the work being in common. The work not only had to meet the above condition but also had to have a sufficiently attractive aeronautical leaning for it to be a motivating tool for students.

The three chosen business lines were on a trike model, three different configurations of an ultralight aircraft that had to be designed: paraglider, hang-glider and autogyro.

Due to the fact that the shared part of the three business lines did not ensure an inter-relationship among all the students of the business group, three departments attached to each business were set up, whose mission was to participate directly in all the business lines. The tasks assigned to each department corresponded to the practical parts of each topic in the subject.

The company structure was planned for groups of 18 students, that is to say, six students per department and six students per business line, as Table 1 shows. With this structure two independent companies were set up with the same objectives. Given their matrix form and given the relationships between projects, the number of design decisions is increased [18] as well as tasks involving each student. In this way, we are not confined only to a limited part of a business line, but must contribute to the progress of all of them and offer solutions that are compatible with the other departments, with which there must also be coordination.

Table 1. Company structure in the first experience

	BL 1	BL 2	BL 3
Dept. 1	S1–S2	S3–S4	S5–S6
Dept. 2	S7–S8	S9–S10	S11–S12
Dept. 3	S13–S14	S15–S16	S17–S18

BL: Business Line. **Dept.:** Department. **S:** Student.

Since the first experience contained a large degree of innovation within the traditional teaching of subjects in the School of Aeronautical Engineering, it was designed for a small number of students (2 companies of 18 students each, as already stated), with the remaining students enrolled in the subject (135 students) forming part of the control group to be used for comparison.

Classes were structured according to a mixed system:

- Two-hour theory classes shared by all students due to the need to compare the two methods.
- Two-hour practical cooperative classes in the CAD lab where group work took place with the availability of the computer tools needed by students (CAD software, calculation applications and word processors).

The control group as well as the group following the innovative experience shared the two weekly hours of theory classes. However, in the 2 hours of practical classes, the first group did individual classroom exercises from each part of the subject, while the second group did cooperative work in the CAD lab.

3.2 Development

The sequence in which the work was carried out followed the portfolio method [19] and methods used in sector companies such as review control systems which ensure the traceability of the work done, always attempting to get as close as possible to professional development. With this, two objectives are met:

1. Students learn from their mistakes by re-doing the parts marked as wrong and letting them control their progress by documenting their state of learning in the subject.
2. Students learn the importance of the changes in engineering design processes and are aware that a good control of these processes and their history ensures perfect design traceability. This is by no means a simple process as students tend to duplicate a lot of information and eliminate what they wrongly assume to be of no use.

Worthy of mention is the students' level of motivation as well as their initial spontaneous organisation. From an educational standpoint, some initiatives were designed to provoke students to become more motivated.

In order to check the level of initiative and collaboration [20] in the first sessions, very open instructions were handed to one of the companies during the information search stage on similar components. This situation caused some initial moments of confusion and indecision but was quickly resolved by the members of the group with most leadership who led the rest of the group to a more active collaboration by sharing the information found by each one. This aspect of collaboration [21] remained deeply ingrained in the organisation in a quite natural way, and, in general, continued to the end of the experience. On the other hand, the second company, quite deliberately, was allowed access to the information that the first company had compiled. Despite the instructions being the same, the absence of the need for and the ease of access to information led to a lower level of cooperation and an increase in individualism.

Another of the positive aspects observed is that students become more familiar with the cooperative design work and application of design criteria that are close to those found in real working life.

Some of the most outstanding difficulties encountered by students are:

- Group functioning problems, above all in decision-making (but not in carrying out the work).
- Difficulty in sharing out the work when given open instructions.
- Poor management of the documentation generated, with the existence of numerous formats and multiple file types. This took up more time and produced some delays.

Figure 1 shows the share of student work hours done by the students, distinguishing group or individual work as well as the place of work.

An average 112 hours' work per student was calculated throughout the 11 teaching weeks that the experience lasted. This time does not include exam preparation work or work done in the 3 teaching weeks that did not include the experience. This means that the total amount of time may be somewhat more than the credits set for the subject (4.6 ECTS credits, the equivalent of 115–138 hours in all). Concerning the distribution of the number of hours of work, the percentage of hours work in the CAD lab stands out (many due to the students' own initiative) and the percentage of purely group work

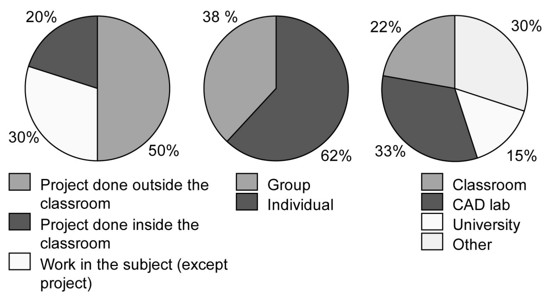

Fig. 1. Time distribution of student work in the first experience.

(38%), which, in the traditional methodology did not exist.

3.3 *Evaluating the methodology*

3.3.1 *Student's evaluation of the experience*

On completion of the project and before setting the final exam in the subject, the students filled in a questionnaire (top score of 5.00) which dealt with aspects of the organisation of the experience and learning.

The proposed experience was novel for the students as they were accustomed to the traditional methods of lectures and problem solving in the classroom. For this reason, the analysis of how they perceived the change in the way of working is important. The teamwork was found to be interesting and satisfactory (4.17 over 5.00), with close relationships being forged between students (4.33) and between students and teachers (4.33). In this respect, the teamwork stands out as the most positive point and it was recognised that it was precisely the innovative experience that enabled it to develop. Also positively scored was the system used to feedback information when marking the work (4.22).

What particularly emerges is that students perceived they had worked more than their fellow-students who had followed the traditional methods (4.44), which can be identified as the main negative aspect as they had to fit in their time with other subjects. Therefore, when faced with the question "Do you think that the mark for the work in the final grade is correct?" 36% of students responded that it was too low.

The global score is fairly satisfactory (4.11), in spite of the negative points indicated, a conclusion that is ratified by the fact that 77.8% of the students would enroll again in the experience if they were at the start of the course and had the opportunity to choose.

3.3.2 *Comparing the results of the scores*

Both the experimental group and the control group that followed the traditional methodology took the same final exam, which had an identical weighting in the global mark. In the study of the target results of the exam two main indicators were considered: the percentage of students who sat the exam and the percentage that passed, shown in Fig. 2. In order to present the situation of subject, firstly the evolution of these indicators in preceding courses should be observed. Taking as reference the data from the 2000–01 to 2005–06 courses (Fig. 14), the pass rate is less than 50% (except in one course 2004–2005) and below 40% in three courses. The last two courses saw slightly higher exam attendance rates as a result of the introduction of some new teaching measures. In other hand, similar result appears in the course 2011–2012 due that this is the last teaching course before new graduate and master's degrees would be implemented. However, in spite of the improvement, the results continued to be unsatisfactory, which motivated the authors to develop the first experience.

For the course 2006–07, the results obtained in the joint exam are reflected in Fig. 2. In the light of the data, two important points become clear:

- All the students who followed the project methodology took the exam, which is indicative of a larger following of the subject on the part of the students.
- The percentage of student passes in the experimental group is significantly higher than for the group that followed the traditional methodology.

Therefore, it may be stated that the experience was positive, with a substantial improvement in results compared to previous years, with a considerable difference between the experimental group and the control group in the two indicators used. As a nuance to this conclusion, it should be pointed out that the "novelty effect" tends to improve students' motivation, and consequently, their results.

Regardless of the difficulties encountered by students to solve the technical problems arising as the project moved forward, group organisation, to which they were not accustomed, emerged as a particularly critical issue. This clearly reveals the need to involve other subjects in experiences that strengthen these general skills.

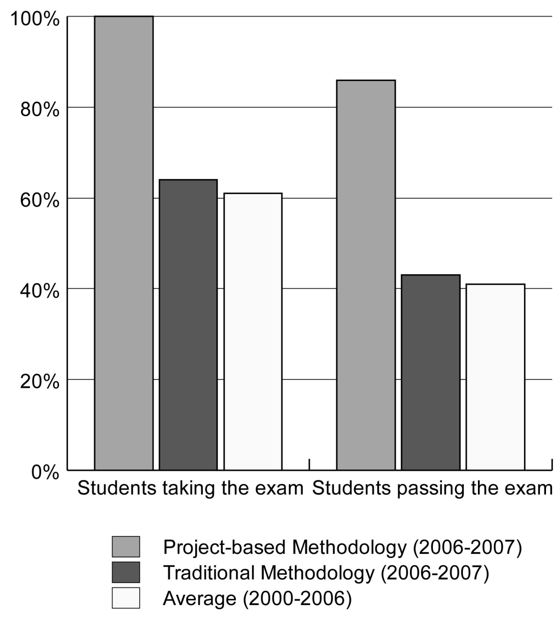

Fig. 2. Data comparison between the experimental group and the control group (with conventional methodology)

The majority of students involved in the project methodology gave a lot of importance to aspects that went beyond those simply directly related to the discipline of the subject, such as aspects that boost communication abilities, relations with fellow-students and teachers, leadership, commitment, responsibility, the ability to share knowledge, etc.

4. Second experience

4.1 Approach

From the point of view of the subject of Graphic Engineering, which is how the course content is currently focused, there are no major differences between the different aeronautical engineering degrees: Aerodynamic & Structure Design (A&SD), Engine Systems (E.S) and Materials & Equipment (M&E). This was designed in this way to enable a more generic and versatile training in the design field. This general approach required seeking problems and projects that were very often remote from the specific content of each degree. This led to a certain loss of interest on the part of students in those projects they considered to be irrelevant to their degree.

The first experience showed that methodology based on teaching projects in large groups enabled projects to be developed with a structure that was common to the three degree courses, with their own applications that were individual to each group.

The very reasons for validating the implementation of new methodologies led to the first experience being voluntarily applied to a small group of students. In this second experience, the project methodology was extended to all the students studying Graphic Engineering. Relations were established among the three degree courses, that is to say, among the individual and group applications, involving different students from different degrees in joint, multidisciplinary projects.

For the total application of this kind of methodology to the subject, two important circumstances arose:

1. The number of students on the three degree courses was not homogeneous, although the proportion in respect of the three courses has varied very little over the last few years, which is a positive point (Fig. 3). This total number of Students taking the exam Students passing the exam students and the proportions between the three degree courses directly conditioned the structure of each work group and therefore, the number of groups (Fig. 5). Each group would be structured departmentally according to a concurrent work methodology directed towards positive collaboration.
2. Aeronautical projects needed to be found whose scope would embrace applications connected with the three degree courses, which in turn could be structured into packets that could be tackled in more detail. These pieces of work would be divided sequentially in order to be able to obtain partial results that would be the starting point for successive milestones.

Generally speaking, the projects and their structure were linked to the configuration of the work groups, which meant seeking projects that could be divided into parts whose relative proportions would fit in with the groups.

These two conditions and the requirement for the projects to be of an aeronautical nature and be attractive to the students [22], gave rise to the creation of 16 companies charged with developing a UAV (Unmanned Air Vehicle), Fig. 4.

4.2 Development

The first stage of the work consisted in establishing the groups (companies) and the responsibilities (roles) of the members of the work groups. Although several authors propose different methods [23, 24], this stage was organised deliberately by the students, who had no problems at all in forming the local groups, that is, the groups of students studying the same course (departments). However, there was a certain difficulty in forming the complete work group (company) in joining the two groups necessary from the other courses.

In order to complete the formation of the group structures (Fig. 5), each engineering degree chose a Team Leader. This choice was open to readjustment if the duties were not carried out so as to systematise the distribution of tasks, by tutoring the students in the different ways and frequencies of holding external meetings. The purpose of these meetings was to encourage students to become quickly integrated and set up convenient channels of communication: full group, department, Team Leader meetings, etc.

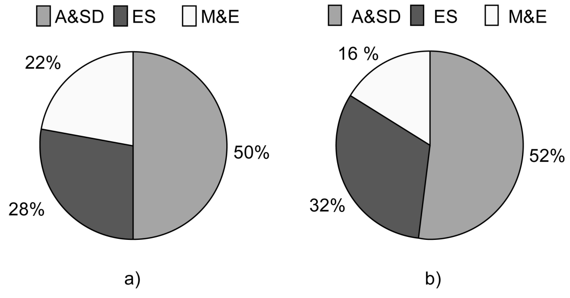

Fig. 3. Student distribution according to degree: a) first experience, b) second experience. A&SD: Aerodynamic & Structure Design, ES: Engine Systems, M&E: Materials & Equipment.

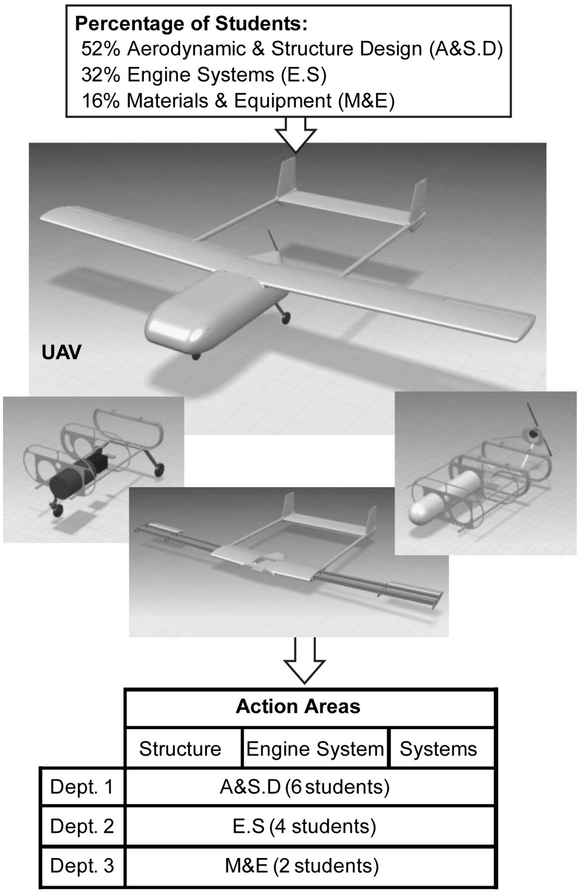

Fig. 4. UAV Project: action areas and departments.

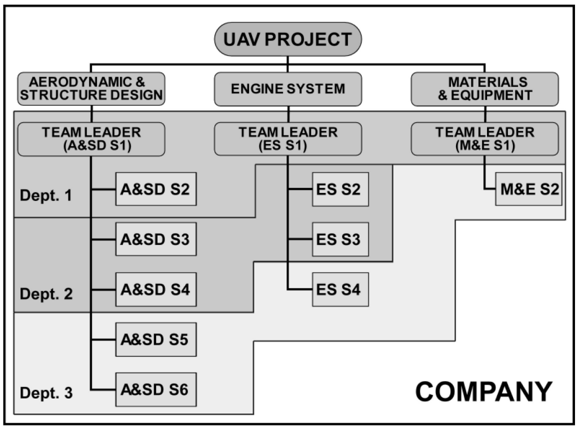

Fig. 5. Distribution of work groups in the UAV project.

Classes were structured, into two one-hour sessions that were devoted to class presentations and discussion, and a single two-hour session that was devoted to cooperative work. Therefore, classrooms were prepared for the cooperative work where the work groups, structured into departments, met and shared the work they had done, while all the teachers (at least two) answered any queries raised by the students (Fig. 6).

It was decided not to do cooperative work at a full group level as the large number of students would make direct communication between the students in each group very difficult. However, it was very important to hold at least three tutorials with all the members of each company to deal with social and academic issues arising from the group's working together.

Fig. 6. Cooperative work session in the CAD lab.

To ensure the smooth running of the work, apart from cooperative work rooms, the students of the different companies were allowed free access to the CAD lab at times other than those planned for the cooperative work classes. This created a permanent work space, as if it were the company's design department, to encourage group work. Moreover, it became a meeting point for developing their own initiatives (meetings, document searches, computer access, etc.).

Having structured and organised the work groups, the work development stages were planned. These would have to be sequenced so that the project would move forward in parallel to the classroom theory classes. Students needed to have the timetable for handing in, presenting and assessing the work:

- Handing in work assessed individually and as a group.
- Classroom presentation sessions of the work done.
- Work done in the graphics room.

All the assessment procedures were combined with tutorials to find out the main problems and then correct the group actions.

4.3 Evaluating the methodology

When the project had been completed but before taking the final exam, the students involved in the experience has to respond to a questionnaire that had been designed to obtain data that would objectively assess the work done.

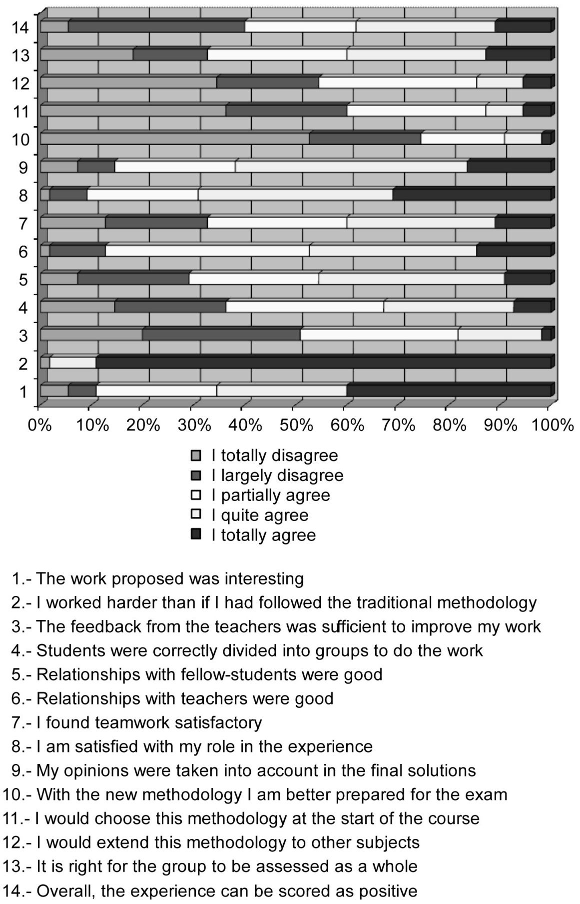

Fig. 7. Student evaluation of the experience.

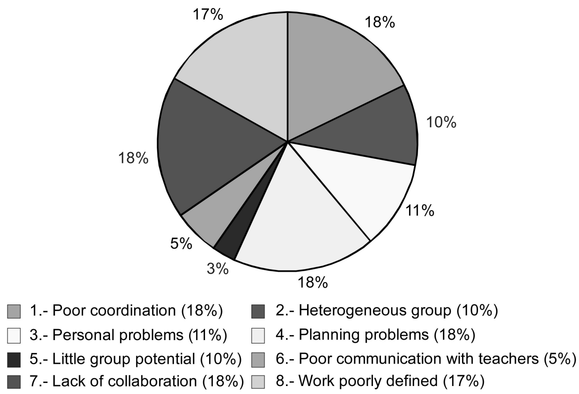

Fig. 8. Evaluation of group work.

The students were of the opinion that the experience had been quite interesting as it had focused on an aeronautical problem that was closely connected with their studies and vocationally relevant (Fig. 7).

In spite of the work done being perceived as satisfactory on the whole, the workload demanded was thought to be very high compared to traditional methods. In addition, the exam preparation was not perceived to be better than if the latter had been followed. From this, it may be deduced that the experience was a leap in methodology to which they were not accustomed. These two issues make students feel disinclined to opt for this new methodology.

The main problems arise from how the group functions regarding coordination and planning, since, as a group, students have clear difficulties in handling situations that they are not used to (Fig. 8).

On the other hand, since the work was of an open nature and attempts to simulate design real design problems, additional problems arose, as the usual educational practice is to solve problems with a closed solution.

The skills assessment (Fig. 9) shows no significant differences, since, on average, students scored the level of achievement of all skills between 3 and 4 (out of 5 points), with a few exceptions. What stands out is the low score for the skills "for motivating a group" and for "leadership". However, the "decision-making", "organising and planning" and "responsibility" skills receive the highest scores in spite of the planning and coordination problems detected in the group.

As a general opinion, one of the aspects worth highlighting was being able to work on a project that was similar to what really happens, which enabled the students to become involved in group dynamics and see the difficulties that arise. Also pointed out as positive aspects were the oral presentation of their work, information searches and learning the computer design applications used in the sector.

One of the negative aspects made clear is the excessive workload (Fig. 10) as well as the lack of definition and lack of clear guidance concerning the project's goals, which required a considerable effort. This led to the work done being regarded as an insufficient reward as the commonly shared perception was that they were not better prepared for the final exam.

The points that were mostly raised when putting forward solutions to improve the experience in coming years were:

- To decrease the workload.
- The number of group members.
- To focus work on more specific goals.
- An assessment method through monitoring group progress.
- Either to consider abolishing the final exam or refocus it on more specific aspects of the experience.

4.4 Conclusions

The most positive aspects arising from the experience are:

1. The nature of group work and sequencing tasks means that the students become more and more involved in carrying out the project. This,

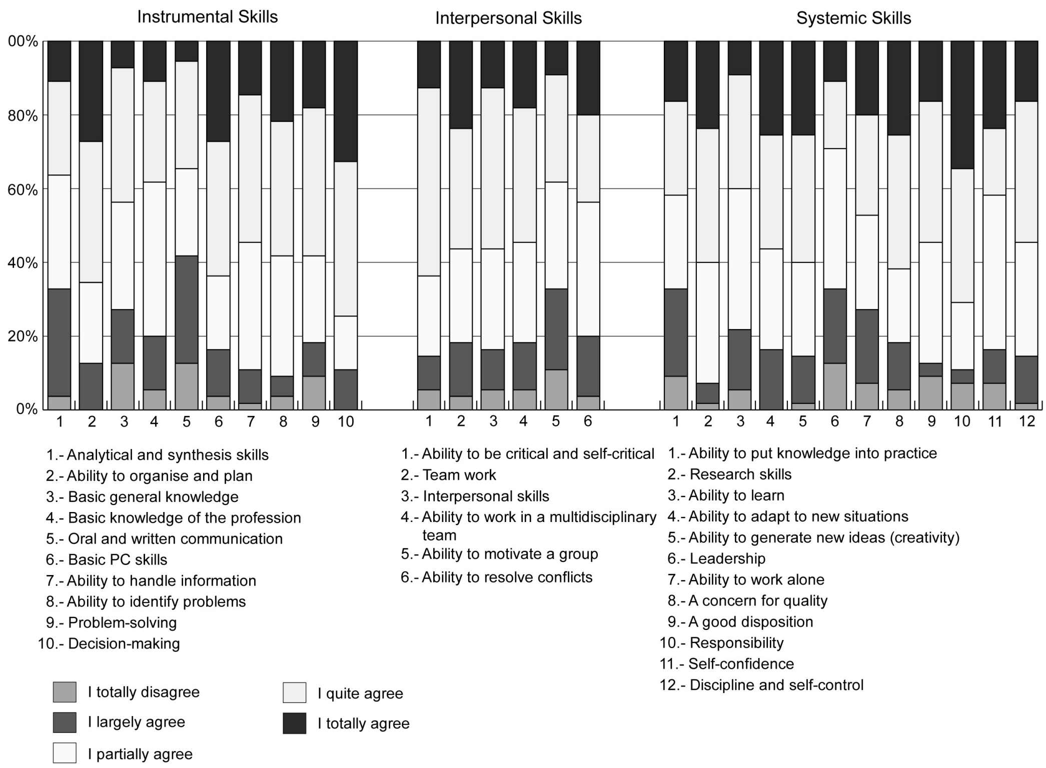

Fig. 9. Evaluation of instrumental skills, interpersonal skills and systematic skills in the second experience in a range of 1 (total disagreement)–5 (total agreement).

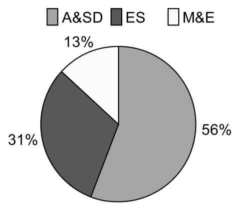

Fig. 10. Proportion of students in each specialisation that stated that the amount of work was higher in the PBL model. A&SD: Aerodynamic & Structure Design, ES: Engine Systems, M&E: Materials & Equipment.

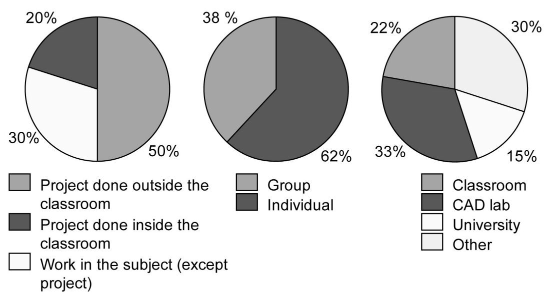

Fig. 11. Final results.

indirectly, leads the students to take the final exam, which, in turn, means that the number of students who fail to take the exam is zero.

2. There is a rise in the number of students who pass (reaching figures of around 90%) as the work assessments are based on four pieces of work to be handed in plus the final exam (Fig. 11).

The most outstanding difficulties found were:

1. In spite of the initial internal organisation of the team, the everyday work gave rise to some problems of group functioning, particularly regarding decision-making (but not in carrying out the work). This, as was the case in the first experience, is probably due to the students' lack of habit of group work. This is a point that must be strengthened as a transversal skill involving various subjects.
2. The students find it difficult to share out the work when open instructions are given. This is a result of the closed approach that has been usually adopted for problems from pre-university education and which continues at University.

It is essential to measure student work time by taking a definition of the teaching based on ECTS credits. Although work inside the classroom is easily quantifiable, work outside the classroom (individual or group) is not easy for the teacher to measure and needs adjusting throughout the course in line with accumulated experience (Fig. 12).

Having completed and analysed the two experi-

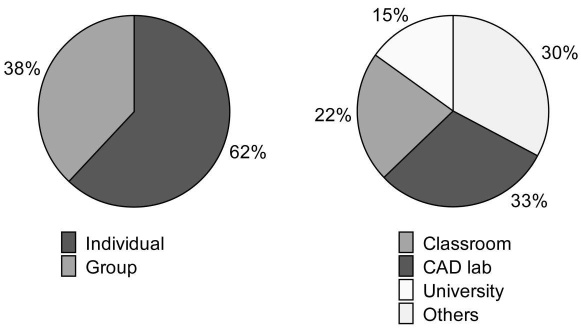

Fig. 12. Time distribution of work during the second experience.

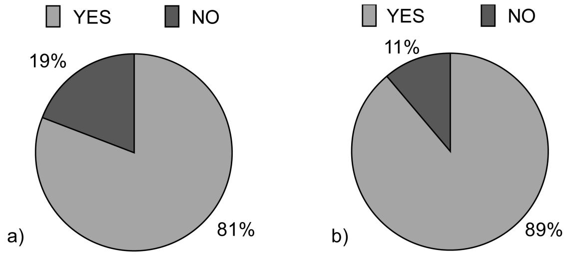

Fig. 13. Students' opinions as to whether the workload with PBL methodology is higher than with traditional methodology: a) first experience and b) second experience.

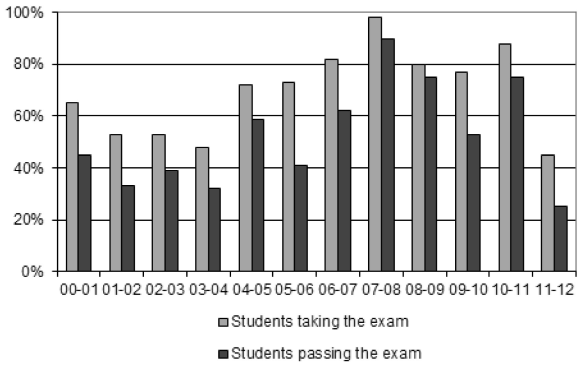

Fig. 14. Evolution of students taking the exam vs. passes per course before applying the methodology (2000–01, 2005–06) and after.

ences, the team of teachers decided to commit themselves to extending the experience to the following courses (2008–09 and 2009–10), since they were aware that the new graduate and master's degrees would be implemented in the 2010–11 course. These new degrees constitute a new action framework, which, although predictable, conditions and modifies the PBL model, as the boundary conditions of the students going on to take the subject are different as well as their level of knowledge.

5. Discussions

Regarding the application of the method to subsequent courses, the following need to be pointed out:

- Without any doubt, the number of students is one of the main problems of the method, particularly when it comes to attending to, monitoring and tutoring the work groups. The number of participants set (between 12 and 18 students) for each group does not have a direct bearing on the problem. The first experience made it clear that it was the excessive number of groups that reduced the quality of the experience. That is the limited time the teacher has to help the groups has a direct bearing on students' expectations (responses 10, 11 and 12, Fig. 8).
- The second problem that arose in the two experiences and in successive years when the method was applied is the students' impression that there is too much work to do (Fig. 2 and response 2, Fig. 8 and Fig. 13) as well as the generalised feeling of not being prepared for the final exam.
- A third interesting point appears to be linked to the fact that it was wished to increase the students' instrumental, systemic and personal skills. This had a negative impact on the consolidation of the most general knowledge in the subject.
- Finally, Fig. 14 shows the evolution of students taking the exam vs. passes per course from 2000 to 2012.

6. Conclusions

One positive aspect is the initial attraction of this methodology, especially in the last final years of the course. This leads the students to become more involved in the subject, thereby reducing the drop-out rate.

From the point of view of the objective of passing the subject, PBL methodology clearly improves the end result by achieving higher pass rates.

Finally, it is important to sit back and reflect in order to avoid an abusive use of this type of methodology. The authors have proved in practice that the subjects included in the same training period need to be coordinated when this method is used. Applying PBL techniques to every subject in isolation clearly overwhelms students' capabilities and makes it impossible to meet the aims of the method.

References

1. J. González and R. Wagenaar, Tuning Educational Structures in Europe, Final Report, Phase One, Technical report, University of Deusto and University of Groningen, 2003, Bilbao (Spain).
2. M. Friesen and K. L. Taylor, Perceptions and experiences of industry co-operators in project-based design courses, *International Journal of Engineering Education*, **23**(1), 2007, pp. 114–119.
3. G. Scott and K. W. Yates, Using successful graduates to improve the quality of undergraduate engineering pro-

grammes, *European Journal of Engineering Education*, (24), 2002, pp. 363–378.
4. R. Martin, B. Maytham, J. Case and D. Fraser, Engineering graduates' perceptions of how well they were prepared for work in industry, *International Journal of Engineering Education*, **30**(2), 2005, pp. 167–180.
5. Bologna Declaration (1999), Bologna Declaration, Joint Declaration of the European Ministers of Education, Technical report, June 1999.
6. R. M. Felder and R. Brent. Learning by Doing, *Chemistry Engineering Education*, **37**(4), 2003, pp. 282–283.
7. D. Boud and G. Feletti, *The Challenge of Problem Based Learning*, Kogan Page, London, U.K., 2007.
8. A. M. Hasna, Problem based learning in engineering design, in *SEFI 36th Annual Conference, European Society for Engineering Education, Aalborg University*, Dennmark, Jul. 2008.
9. R. Hadgraft, Problem-based learning: A vital step towards a new work environment, *International Journal of Engineering Education*, **14**(1), 1998, pp. 14–23.
10. L. Dym Clive, A. M. Agogino, D. D. Frey and L. J. Leifer, Engineering design thinking, teaching, and learning, *Journal of Engineering Education*, **94**, 2001, pp. 103–120.
11. S. Finger, D. Gelman, A. Fay and M. Szczerban, Assessing Collaborative Learning in Engineering Design, *International Journal of Engineering Education*, **22**(3), 2006, pp. 637–644.
12. V. Wilczynski and J. J. Jennings, Creating Virtual Teams for Engineering Design, *International Journal of Engineering Education*, **19**(2), 2003, pp. 316–327.
13. P. C. Powell, Assessment of team-based projects in project-led education, *European Journal of Engineering Education*, **29**(2), 2004, pp. 221–230.
14. D. Gillet, A. V. Nguyen Ngoc and Y. Rekik, Collaborative web-based experimentation in flexible engineering education, *IEEE Transactions on Education*, **48**(4), 2005, pp. 696–704.
15. J. González and R. Wagenaar, Tuning educational structures in Europe II, final report, universities' contribution to the bologna process. Technical report, University of Deusto, Bilbao (Spain), 2005.
16. R. Fruchter, Dimensions of Teamwork Education. *International Journal of Engineering Education*, **17**(4–5), 2001, pp. 426–430.
17. J. L. Cano, I. Lidon, R. Rebollar, P. Roman and M. J. Saenz, Student Groups solving real-life projects, a case study of experiential learning, *International Journal of Engineering Education*, **22**(6), 2006, pp. 1252–1260.
18. K. N. Otto and K. L. Wood, *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall, Upper Saddle River, N. J., 2001.
19. H. C. Barret, The e-portfolio: a revolutionary tool for education and training?, in *International Conference on the e-portfolio*, Poitiers (France), Oct. 2003.
20. N. J. Delson, Increasing Team Motivation in Engineering Design Courses, *International Journal of Engineering Education*, **17**(4–5), 2001, pp. 359–366.
21. O. Göl and A. Nafalski, Collaborative learning in engineering education, *Global Journal of Engineering Education*, **11**(2), 2007, pp. 173–180.
22. F. Gandía, M. Barcala, A. Rodríguez and J. Pérez. The design and building of a UAV: An actual engineering project for student cooperative work. in *INTED*, Valencia, Spain, 2008.
23. B. Gross-Davis, *Tools for Teaching*, Jossey-Bass, San Francisco, CA, 1993.
24. A. Andersen, Preparing engineering students to work in a global environment to co-operate, to communicate and to compete. *European Journal of Engineering Education*, **29**(4), 2004, pp. 549–558.

Jose Luis Perez-Benedito is a Full Professor in the Departamento de Aeronaves y Vehículos Espaciales at the Universidad Politécnica de Madrid. He has focused on a range of innovative PBL projects. He has authored and co-authored several papers in engineering education, and is actively involved in innovative education projects. He belongs to the Visual Graphics Group (V.G.G.) educational innovation group.

Javier Pérez-Álvarez has developed his professional career in engineering consulting, aerospace engine flight test instrumentation, aerospace engine dressing and spacecraft pay-load structure support. Currently, he is a Full Professor of Mechanical Design at the Universidad Politécnica de Madrid and develops engineering studies for different aeronautical firms. His fields of interest are the aeronautical industry, aircraft and spacecraft design, mechanical design and the application of new educational approaches in university studies. He belongs to the V.G.G educational innovation group and to IDR, Instituto Universitario de Microgravedad Ignacio da Riva.

María Jesús Casati is a Full Professor in the Departamento de Aeronaves y Vehículos Espaciales at the Universidad Politécnica de Madrid. She is involved in projects in Mechanic of Materials and Structures and is authored of several technical papers. She has coordinated several innovative education projects. She belongs to the Visual Graphics Group (V.G.G) educational innovation group.